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(19)

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(54) A PIPELINE FOR THE TRANSPORT OF COLD LIQUIDS

(71) We, SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ N.V., a company organised under the laws of The Netherlands, of 30 Carel van Bylandtlaan, The Hague, The Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly descibed in and by the following statement:—

The present invention relates to pipelines for the transport of cryogenic liquids, that is liquids at very low temperatures, in particular liquefied natural gas, and it is concerned with an improved form of such pipelines for use under water or on land.

As a result of the low temperatures of the liquids to be transported (in the case of liquefied natural gas about —160°C) and the likely use of the pipeline under water, a pipeline of this type has to meet stringent requirements. The choice of constructional material for such pipelines is limited to those materials which possess sufficient ductility at the low temperatures which arise during usage. Materials which meet this requirement at the low temperature of liquefied natural gas are, for instance, 9% nickel-steel, austenitic steel and aluminium. In addition, the low temperatures cause large displacements through shrinkage. Cooling of a pipeline having a length of 1 km from ambient temperature to minus 160°C will cause a displacement through shrinkage of approximately 2 m in the case of a 9% nickel steel line and of approximately 4 m in the case of an aluminium line.

In view of the low temperature of the liquid to be transported, the pipeline should, of course, have good heat-insulating properties. When using the pipeline under water a good water-tight heat-insulation is required, and it is desirable that, if water leaks into the insulation locally, the line should remain operational without too large a heat inflow till a convenient moment for repair. In addition, underwater lines require to be robust so that laying, which is mostly done from a vessel, does not cause damage to the line and/or the heat-insulation.

A known pipeline for cold liquids comprises a plurality of sections each comprising an inner pipe and a co-axial outer pipe having a larger diameter than the inner pipe, adjacent ends of the respective inner pipes of the sections being joined together by bellows, and a heat-insulating material being present in the space between the inner and outer pipes. Shrinkage of the inner pipe when cold liquid passes through it is absorbed without significant stresses arising by the bellows between successive inner pipes. As an alternative to bellows connections, the inner pipe can be of corrugated form for part or all of its length whereby the shrinkage is taken up by the inner pipe itself. However, bellows are weak points in a pipeline and repair or replacement is often difficult or impossible, especially in the case of submerged pipelines. Also, bellows (or corrugations in the pipe itself) have the disadvantage of causing extra flow resistance; and corrugated pipes can only be produced by one of the few specialized manufacturers.

According to the present invention there is provided a pipeline section comprising a non-corrugated inner pipe, an outer pipe spaced from and co-axial with said inner pipe and heat-insulating material within the space between said pipes, said pipeline section being adapted to be joined with at least one other such section to form a pipeline suitable for the transport of liquids, the sections when so joined having at least their respective inner pipes rigidly joined together at the juncture(s) between sections, the inner and outer pipes of said

section being so rigid and being so rigidly connected together at at least two axially spaced positions within the section that a high axial compression stress is present either in the outer pipe or in the inner pipe either at normal ambient temperature or at the low temperature of the section subsisting during the passage of a cryogenic liquid therethrough.

A first embodiment of a pipeline for the transport of cryogenic liquids as just defined is characterized in that the inner pipe and the outer pipe of each section are so connected together that, when the pipes are at ambient temperature, no, or only slight, axial stresses occur in the inner and outer pipes, but when the inner pipe is cooled to normal operating temperatures (i.e. the normal situation during transportation of cold liquid through line), an axial tensile stress is present in the inner pipe and an axial compression stress is present in the outer pipe.

This first embodiment will be designated below as the strained type of line.

A second embodiment of a pipeline in accordance with the present invention is characterized in that the inner and outer pipes of each section are so connected together that when the pipes are at ambient temperature, the outer pipe and the inner pipe are prestressed in such a manner that the outer pipe is under axial tensile stress and the inner pipe is under axial compression stress.

This second embodiment will be designated below as the prestressed type of line.

The present invention will now be described with reference to the accompanying drawings in which:—

Figure 1 represents a diagrammatic longitudinal cross-section of an embodiment of a section of a line of the restrained type;

Figure 2 is a diagrammatic longitudinal cross-section of an embodiment of a section of a line of prestressed type;

Figure 3 is a diagrammatic longitudinal cross-section of an embodiment of a connection for connecting together the inner and outer pipes within a section.

Figure 4 is a diagrammatic longitudinal cross-section of an embodiment of a coupling between two line sections of the restrained type;

Figure 5 is a diagrammatic longitudinal cross-section of an embodiment of a coupling between two line sections of the prestressed type;

Figure 6 shows a pipeline consisting of sections.

Figure 7 shows another form of a pipeline consisting of sections.

The pipeline section shown in Figure 1 comprises an inner pipe 1, manufactured from a suitable material retaining its ductility at the low temperature of the liquid gas, for example, 9% nickel steel. Co-axial with the inner pipe 1 is an outer pipe 2 having a larger diameter than the inner pipe 1. This pipe 2 is made from a suitable material, for example, carbon steel. The ends of the inner pipe 1 and the outer pipe 2 are connected by means of connections 3 and 4, for example, by means of the welded joints as indicated in the figure. The connections 3 and 4 are also manufactured from a suitable material, for example part 3 from 9% nickel steel and part 4 from stainless steel.

The space between the inner and outer pipe is filled with a suitable heat-insulating material 5, for example polyurethane foam, preferably with closed cells. If desired, other suitable plastics foams, such as PVC-foam, may also be used.

The manufacture of the pipeline section just described is as follows.

The connections 3 and the connections 4 are first welded to one end of the inner pipe 1.

The inner pipe 1 is subsequently provided with a slide layer (not shown) which is several millimetres thick and does not adhere to the inner pipe 1. This layer consists of a suitable material, for instance, a felt or a fabric made from, for example, polypropylene or glass fibre. Plastics foil or paper or jute may also be used. The object of the slide layer is to allow the inner pipe 1 to move axially (as a result of temperature gradients in the longitudinal direction of the pipe) relative to the heat-insulating material 5. It is noted that the said slide layer may, if desired, be omitted. It is also possible to apply a slide layer between the outer pipe and the heat-insulating material instead of between the inner pipe and the heat-insulating material.

The plastics foam is subsequently applied to the slide layer. In the absence of a slide layer, the plastics foam is applied direct to the inner pipe 1. Polyurethane foam, for example, is applied by spraying, so that a heat-insulating layer 5 is formed.

If desired, a suitable fabric or fibrous material 6, for example a glass-fibre fabric, may be incorporated into this heat-insulating layer 5 as a crack formation of the heat-insulating material 5. Instead of a glass-fibre fabric it is also possible to use a fabric of a different suitable material, for example linen, cotton, jute, hemp. Instead of a fabric, fibres of the said materials may also be used. It is also possible to use metal matting, manufactured from, for example, stainless steel.

After the insulating layer 5 has been applied, the outer pipe 2 is arranged and joined by welds to one connection 4. The

connections 3 and 4 are then welded to the other end and connection 4 is welded to the outer pipe 2. The outer pipe 2 is arranged in such a way that at normal ambient temperatures there is no, or only slight, axial tensile stress or axial compression stress on the outer and the inner pipe.

If desired, a small space may be present between the outer pipe 2 and the insulating layer 5.

A single section of the pipeline is shown in Figure 1. The pipeline itself is built up of a number of sections according to Figure 1 which are connected in series.

In order to counteract floating up of the line when used under water, the outer pipe 2 may be provided on the outside with a concrete jacket (not shown) or other ballast means. It is also possible to attach anchoring means to the outer pipe 2.

When the pipeline section according to Figure 1 is taken into normal use, i.e. when cold liquid (for example liquid natural gas at approximately minus 160°C) is passed through the inner pipe 1, this pipe will cool and shrink. Since the ends of the inner pipe 1 are connected to the ends of the outer pipe 2, axial tensile stress will develop in the inner pipe 1 and axial compression stress in the outer pipe 2. There is no risk of buckling (crippling) of the outer pipe 2 while under axial compression stress owing to the fact that the outer pipe 2 is supported elastically by the inner pipe 1 via the heat-insulating material 5.

The outer pipe 2 protects the heat-insulting material 5 against damage both during transport and during laying of the pipeline. In addition, the outer pipe 2 prevents water from penetrating into the heat-insulating material 5.

The pipeline section shown in Fig. 2 comprises an inner pipe 1, manufactured from a suitable material which retains its ductility at the low temperature of the liquid gas, for example 9% nickel steel. An outer pipe 12 having a larger diameter than the inner pipe 11 is arranged co-axially with the inner pipe 11. The outer pipe 12 is made from a suitable material, for example, carbon steel. Connections 13 are secured to the inner pipe 11, for instance by welded joints. At one end of the line section a connection 14 is welded to the connection 13. At the other end of the line section an element 17 provided with a flange 19 is welded to the connection 13. The connections 13 are made from a suitable material, for example, 9% nickel steel. The connection 14 is made from, for example, stainless steel, as is the element 17.

The outer pipe 12 is welded at one end to the connection 14. At the other end the outer pipe 12 is provided with a flange 20 which is secured to the flange 19 by means of bolts 18.

The space between the inner and outer pipe is filled with a suitable heat-insulating material 5, for example polyurethane foam, preferably with closed cells. If desired, other suitable plastics foams, such as, for example PVC-foam, may be used.

The pipeline section just described is constructed as follows: The connections 13 are first welded onto the inner pipe 11 and a connection 14 is subsequently welded to the part 13 at one end of the line section.

The inner pipe 11 is then provided with a slide layer (not shown) which is several millimetres thick and does not adhere to the inner pipe 11. This slide layer consists of a suitable material for example a felt or a fabric made from e.g. polypropylene or glass fibre. Paper or jute may also be used. The object of the slide layer is to allow the inner pipe 11 to move axially (as a result of temperature gradients in the longitudinal direction of the pipe) relative to the heat-insulating material 15. It should be noted that the said slide layer may, if desired, be omitted.

The plastics foam is subsequently applied to the slide layer. If the slide layer is not used, the plastics foam is applied direct to the inner pipe 11. Polyurethane foam, for example, is applied by spraying, so that a heat-insulating layer 15 is formed. Alternatively, foaming in situ may be applied or shells of polyurethane foam may be used.

If desired, a suitable fabric or fibrous material 16, for example, a glass-fibre fabric, may be incorporated as a crack arrester into this heat-insulating layer 15 in order to arrest crack formation of the heat-insulating material 15. Instead of a glass-fibre fabric, it is also possible to use a fabric of a different suitable material, for example linen, cotton, juste, hemp. Instead of a fabric, fibres of the said materials may be also be used. It is also possible to use metal matting, manufactured from, for example stainless steel.

After the insulating layer 15 has been completed, the outer pipe 12 is arranged. One end of the outer pipe 12 is welded to the left-hand connection 14. A part 17 with a flange 19 is welded to the right-hand connection 13. The flange 20 is secured to the flange 19 by means of bolts 18. The bolts 18 are subsequently tightened to bring the outer pipe 12 under a relatively large axial tensile stress. This results in the inner pipe 11 being subjected to axial compression stress. If desired, packing may be provided between the flanges 19 and 20 to ensure a gas-tight seal.

It was stated above that prestressing the inner pipe and outer pipe is effected by means of flanges and bolts. It will be evident

that prestraining can be achieved in numerous other ways. Consequently, the invention is not limited to prestraining of the inner pipe and the outer pipe by means of flanges and bolts.

A single section of the pipeline is shown in Figure 2. The pipeline itself is built up of a number of sections shown in Figure 2, which are connected in series.

When the pipeline section according to Figure 2 is taken into normal use, i.e. when cold liquid (for example liquid natural gas at approximately minus 160°C) is passed through the inner pipe 11, this pipe will cool and shrink. This means that the prestress, i.e. the axial compression stress in the inner pipe, will be reduced. Simultaneously the prestress, i.e. the axial tensile stress, in the outer pipe will be reduced. The magnitude of the prestress applied and the temperature of the cold liquid which is passed through the inner pipe 11 determine the magnitude of the axial stresses remaining in the inner pipe and outer pipe. For example, a relatively small axial compression stress in the inner pipe 11 and a relatively small axial tensile stress in the outer pipe 12 may remain. In some cases the axial stresses may disappear completely both in the inner pipe 11 and in the outer pipe 12 as a result of cooling of the inner pipe 11 or the axial stresses may even change sign.

There is no risk of buckling (crippling) of the inner pipe 11 or outer pipe 12 while under axial compression owing to the fact that the inner pipe and outer pipe support each other elastically via the heat-insulating material 15.

The outer pipe 12 protects the heat-insulating material 15 against damage, both during transport and during laying of the pipeline. Moreover, the outer pipe 12 prevents water form penetrating into the heat-insulating material 15.

When a pipeline is built up by connecting a number of pipeline sections of the type according to Figure 1 or Figure 2 in series, the displacements of the inner pipes 1 or of the inner pipes 11 through expansion or shrinkage along the pipeline will be relatively small. The displacements will be determined by the lengths of the line sections used. This means that a relatively large temperature gradient along the pipeline is admissible. This is of particular importance when bringing the line into operation and taking the line out of operation.

In all the above-mentioned embodiments of pipeline section, the connections between the inner pipe and the outer pipe can be effected in numerous ways. The connections between the ends of the inner pipe and outer pipe shown in Figures 1 and 2 are only given to elucidate the principle underlaying the invention.

A preferred connection for connecting the inner and outer pipes is shown in Figure 3.

This connection comprises a conical element 27, having a shape of a truncated hollow cone, one end of which is attached by welding on to the outer surface of the inner pipe 21. This conical element 27 is made of a suitable material, for example, 9% nickel steel. An inner ring 28 is attached by welding onto the other end of the conical element 27. This inner ring 28 is manufactured from, for example, stainless steel. An outer ring 26 is fitted onto the inner ring 28 and rigidly secured to the latter by welding. The outer ring 26 is made from, for example, carbon steel. If desired, the outer ring 26 is provided with cams 29. These cams 29 may be used if it is desired to prestress the line or line section in advance.

Figure 4 shows a coupling between two line sections of the restrained type, i.e. line sections based on the principle shown in Figure 1.

The inner pipes 21 are connected to the inner pipes 1 of the line sections by means of welded joints 30, while the outer rings 26 are connected to the outer pipes 2 of the line sections by means of welded joints 31. As mentioned above, the spaces between the inner pipes 1 and the outer pipes 2 are filled with a heat-insulting material 5, for example, polyurethane foam.

The inner pipes 21 are interconnected by a welded joint 32. The outer rings 26 are connected by means of a ring 33. This ring 33 may comprise 2 or more shells welded together.

The ring 33 is made from a suitable material, for example, carbon steel. The ring 33 is connected on either side of the outer ring 26 by means of welded joints 34 and 35. The space bounded by the inner pipes 21, the conical elements 27, the outer rings 26 and the ring 33 is also filled with heat-insulating material 55, for example polyurethane foam. This heat-insulating material may be in the form of shells; it may be applied *in situ* by spraying or by foaming. The heat-insulating material 5 or 55 may, if desired, be reinforced by a fabric or fibrous material (crack arrester) in the manner described above.

The ring 33 is not prestressed, nor are the outer pipes 2 and the outer rings 26. Consequently, these parts are simply welded together.

The rings 26 are not provided with cams 29; there being no need to do so in this case since prestressing in advance is not required.

Figure 5 shows a coupling between two line sections of the prestressed type, i.e. two line sections based on the principle shown in Figure 2.

In the line section shown on the left- and right-hand sides in Figure 5, the inner pipe 11 is connected with the outer pipe 12 in such a manner that the outer pipe 12 is under tension and the inner pipe is under compression (if the inner and the outer pipe are at normal ambient temperature). The outer ring 26 is connected to the outer pipe 12 by welded joint 41 and the inner pipe 21 with the inner pipe 11 by means of a welded joint 42.

Heat-insulating material 15, for example polyurethane foam, is present between the inner pipe 11 and the outer pipe 12 in the manner described above.

The inner pipes 21 are connected by means of a welded joint 43. After the joint 43 has been completed heat-insulting material 44, for example polyurethane foam, is applied. The heat-insulating material may be applied in situ by spraying or by foaming or in the form of shells.

A ring 45, which may consist of two or more shells is subsequently welded to the right-hand outer ring 26 by means of a welding joint 46. The shells forming the ring 45 are also welded together. Cams 47 are secured onto the outer surface of the ring 45. However, instead of the cams 47 ring segments may be used.

After the ring 45 has been secured, such an axial force is exerted on the cams (or ring segments) 47 and 29 that the left-hand rim of the ring 45 comes into contact (see dotted position) or virtual contact (so that the opening X disappears) with the right-hand rim of the left-hand outer ring 26, the said rims being subsequently welded together. Alternatively, this object may also be achieved by exerting the said axial force on the left- and right-hand cams 29.

After the latter joint has been welded and the axial force exerted from outside has been eliminated, the ring 45 is under axial tensile stress and the parts of the inner pipes 21 situated near the weld 43 and between the conical elements 27 are under axial compression stress, The resultant coupling is therefore prestressed, as are the relevant line sections. It should be noted that the ring 45 is made from a suitable material, for example carbon steel.

It should be noted that in the case of couplings as shown in Figurres 4 and 5, the welds 32 and 43 may each be replaced by a flange coupling, if desired.

Figures 6 and 7 show methods for the construction of a pipeline consisting of sections.

The connection comprising the parts 50, 51, 52, 53, 54, 55, which is provided with an insulation 71, is produced in advance. A pipeline section consisting of an inner pipe 58, an outer pipe 57 and an insulating material 60 has already been laid in place. The inner pipe 53 of the said connection is subsequently welded (weld 59) to the inner pipe 58. Then an insulating material 72 is applied. An outer ring 61 (consisting of shells) is connected to the outer ring 50 by means of a weld 62.

Cams 64 are present on the outer pipe 57 and cams 63 on the outer ring 61. An axial force is exerted on these cams, as a result of which the ring 61 is stretched and the space between the outer pipe 57 and the outer ring 61 is eliminated. A weld 65 is subsequently made at the place indicated by the broken line, connecting the parts 57 and 61. The axial force is then eliminated from the cams 63 and 64, leaving an axial tensile stress in the parts 58 and 53.

Then, the next section is built up. An inner pipe 66 is joined to the inner ring 52 by a weld 67. Heat-insulation 68 is arranged, and an outer pipe 69, whereupon a weld 70 is made. The operations described above are then repeated at the right-hand side of the pipe section consisting of the parts 66 and 69, and so on until the pipeline has attained the desired length.

The method according to Figure 7 is as follows:

The connection 75, 76, 77, 78, 79 is produced in advance. A pipeline section comprising an inner pipe 81, an outer pipe 83 and an insulating material 82 has already been laid in place. A ring 85 (optionally in sections) is arranged on the inner pipe 81 and welded thereto by a weld 86. Then insulation 95 is applied. The connection 75-79 is subsequently slid on the inner pipe 81 against the ring 85. Cams 84 are present on the outer pipe 83 and cams 80 on the outer ring 75. An axial force is then exerted via the said cams as a result of which the ring 75 is stretched axially and the space between the parts 75 and 83 disappears. A weld 87 is then made at the place indicated by the broken line, connecting the parts 75 and 83. Finally, the axial force is eliminated from the cams, leaving an axial tensile stress in the parts 75 and 83 and an axial compression stress in the inner pipe 81.

A ring 88 (optionally in sections) is now arranged on the inner pipe 81 and welded thereto by a weld 89. An inner pipe 90 is welded to the inner pipe 81 by a weld 91. An insulation 92 is arranged and finally the outer pipe 93 which is welded to the outer ring 75 by a weld 94.

The operations described above are then repeated at the right-hand side of the pipe section, consisting of the parts 92 and 93, and so on until the pipeline has attained the desired length.

If use is made of a pipeline based on the above principles, and running from a point on land to a point offshore (for instance near a jetty, mooring-island or mooring-buoy),

the end of the pipeline may, if desired, be anchored to the sea-bed at the latter point, while the end of the pipeline on land may be secured freely movable axially.

Prestressing of the line sections or of a "growing" pipeline during assembly may be effected in various ways, for example mechanically and hydraulically by means of hydraulically driven pipe clamps with which the outer pipe is brought under tension and the inner pipe under compression.

It is also possible to use a thermal method. In this method, the inner pipe is cooled or the outer pipe is heated, the ends of the inner pipe and the outer pipe being subsequently connected. Cooling may, for example, be effected with the aid of solid CO_2 or liquid N_2.

WHAT WE CLAIM IS:—

1. A pipeline section comprising a non-corrugated inner pipe, an outer pipe spaced from and co-axial with said inner pipe and heat-insulating material within the space between said pipes, said pipe-line section being adapted to be joined with at least one other such section to form a pipeline suitable for the transport of cryogenic liquids, the sections when so joined having at least their respective inner pipes rigidly joined together at the juncture(s) between sections, the inner and outer pipes of said section being so rigid and being so rigidly connected together at at least two axially spaced positions within the section that a high axial compression stress is present either in the outer pipe or in the inner pipe either at normal ambient temperaure or at the low temperature of the section subsisting during the passage of a cryogenic liquid therethrough.

2. A pipeline section as claimed in claim 1, wherein the inner and outer pipes are so connected together that, when the pipes are at ambient temperature, no, or only slight, axial stresses occur in the inner and outer pipes, but when the inner pipe is cooled to normal operating temperatures an axial tensile stress is present in the inner pipe and an axial compression stress is present in the outer pipe.

3. A pipeline section as claimed in claim 1, wherein the innner and outer pipes are so connected together that, when the pipes are at ambient temperature, the outer pipe and the inner pipe are prestressed in such a manner that the outer pipe is under axial tensile stress and the inner pipe is under axial compression stress.

4. A pipeline section as claimed in any one of claims 1 to 3, wherein the heat-insulating material is a plastics foam.

5. A pipeline section as claimed in claim 4, wherein the plastics foam has closed cells.

6. A pipeline section as claimed in claim 4 or 5, wherein the plastics foam is a polyurethane foam or a PVC-foam.

7. A pipe line section as claimed in any one of claims 1 to 6, wherein the inner and outer pipes are connected together at the ends of the section.

8. A pipeline section as claimed in any one of claims 1 to 7, wherein a slide layer is present between the inner pipe and the heat-insulating material or between the outer pipe and the heat-insulating material.

9. A pipeline section as claimed in claim 8, wherein the slide layer comprises a felt or polypropylene fabric or glass fibre.

10. A pipeline section as claimed in claim 8, wherein the slide layer consists of paper.

11. A pipeline section as claimed in claim 8, wherein the slide layer consists of jute.

12. A pipeline section as claimed in any one of claims 4 to 11, wherein the plastics foam is applied by spraying.

13. A pipeline section as claimed in any one of claims 4 to 11, wherein the plastics foam is applied *in situ* by foaming.

14. A pipeline section as claimed in any one of claims 4 to 11, wherein the plastics foam is in the form of pre-formed shells.

15. A pipeline section as claimed in any one of claims 1 to 14, wherein the inner pipe consists of nickel steel.

16. A pipeline section as claimed in any one of claims 1 to 14, wherein the inner pipe consists of aluminium.

17. A pipeline section as claimed in any one of claims 1 to 16, wherein the outer pipe consists of carbon steel.

18. A pipeline section as claimed in any one of claims 1 to 17, wherein the inner and the outer pipes are connected together in a gas-tight manner.

19. A pipeline section as claimed in claim 1 and substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

20. A pipeline comprising a plurality of sections as claimed in any one of claims 1 to 19 joined end to end.

21. A pipeline substantially as hereinbefore described with reference to Figure 6 or Figure 7 of the accompanying drawings.

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1348318 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

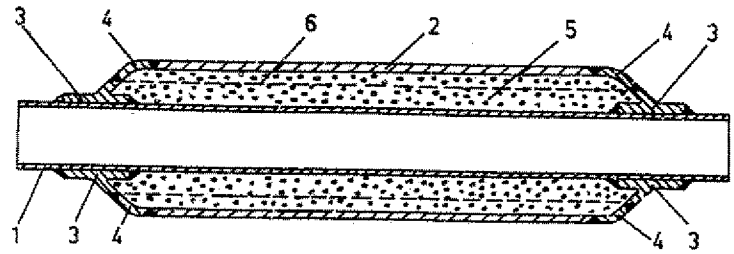

FIG.1

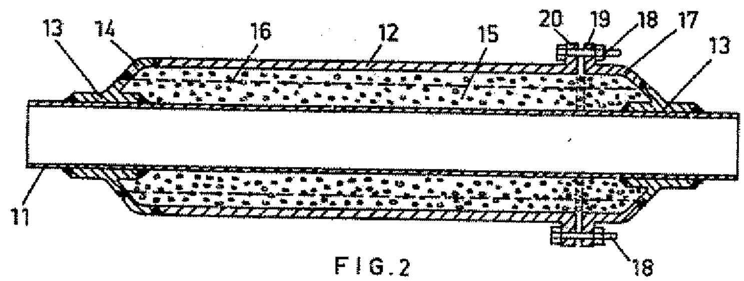

FIG.2

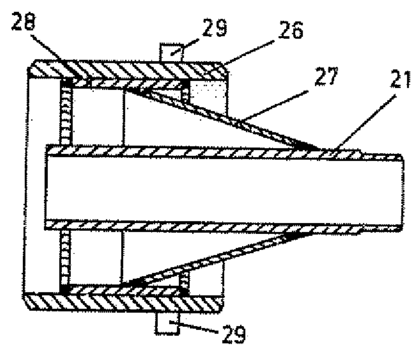

FIG.3

1348318 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

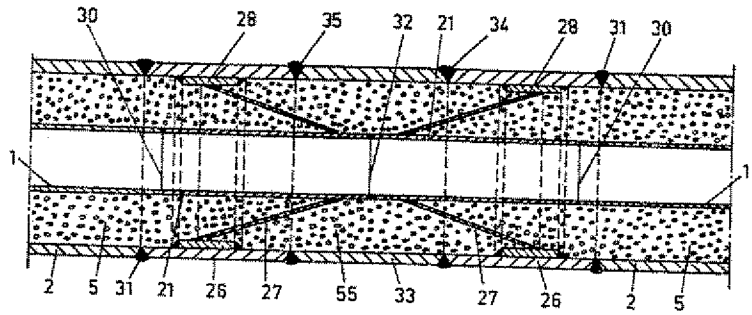

FIG.4

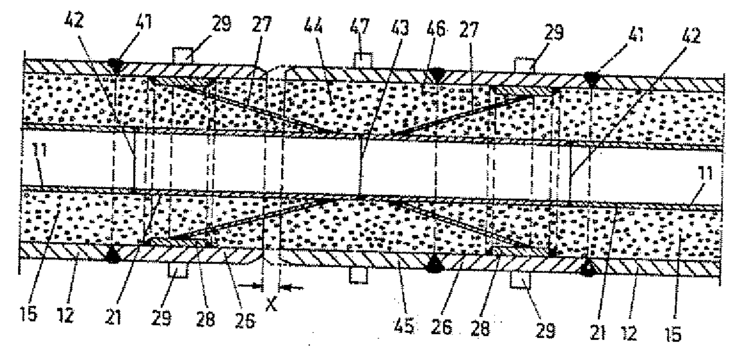

FIG.5

1348318 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

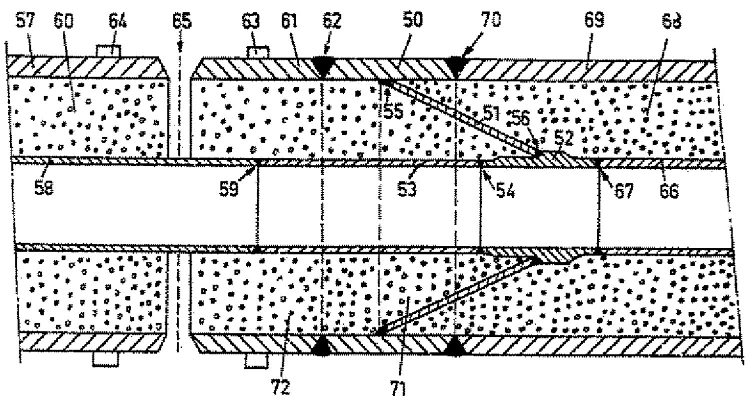

FIG.6

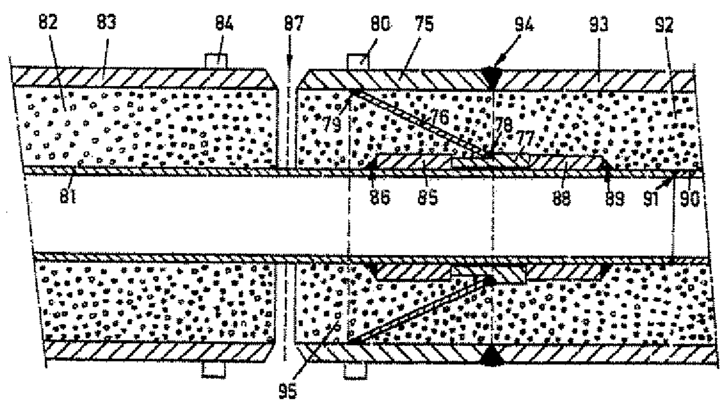

FIG.7